BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D. C. 20036

SUBJECT: ATM Alternative Mission Study:
Impact of Computer Systems
Case 620

DATE: August 9, 1968

FROM: R. T. Kleiner
B. H. Liebowitz
P. S. Schaenman

ABSTRACT

The spaceborne and MCC-H computer systems do not seem to pose any major problems for an Apollo Telescope Mount Alternative AAP mission. The spaceborne computers are estimated to have adequate memory and speed margins with respect to presently identified requirements. The unaugmented MCC-H systems impose the same constraints as for any other AAP mission. The conclusion is that if the baseline AAP missions can be handled, so could the ATM Alternative Mission.

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MEMORANDUM FOR FILE

An alternative Apollo Telescope Mount mission has been proposed for AAP in which a CM-SM/LM-ATM combination is flown in a high inclination orbit, independent of any Orbital Workshop. This memorandum considers the potential impact of the spaceborne digital computers and the ground-based computer systems at Mission Control Center-Houston on that mission.

I. SPACEBORNE COMPUTERS

A. General Functions

The alternative AAP mission would require the use of from three to five spaceborne digital computers. The Launch Vehicle Digital Computer (LVDC), the Lunar Module Guidance Computer (LGC), and the Command Module Computer (CMC) are the identical machines used in Apollo. Their functions are basically similar to those in Earth Orbital Apollo missions: the LVDC controls the trajectory of the launch vehicle; the LGC performs guidance and navigation functions for attaining the proper orbit prior to achieving rendezvous; and the CMC performs guidance and navigation for achieving rendezvous of the CM-SM with the LM, getting to the mission orbit with the combined spacecraft, and for reentry.

A fourth computer, the Apollo Telescope Mount Digital Computer (ATMDC), has been proposed by MSFC to support various ATM-related functions such as pointing control, momentum management, and display driving.*

The potential fifth computer, the Abort Electronics Assembly (AEA), is the small digital computer that is part of the Abort Guidance System in the LM. The function of this computer has not yet been decided for AAP.

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*These functions could be provided by the LGC, but the authors agree with MSFC's recommendation that a new, small computer be purchased. Procurement of the new computer is currently awaiting NASA Headquarters approval.

B. Memory Margins

The memory capacities for each of the above computers are given in Table 1, along with estimated margins available for new programs for the ATM Alternative Mission. The estimates given for the LVDC assume that the launch vehicle requirement will be about the same as for an Apollo 200-series mission. The LVDC memory can also be expanded by adding two memory modules to provide an additional 4000 words if necessary. The numbers given for the ATMDC are based on MSFC's estimated 4000 words of currently defined ATM software requirements, and their desire for a machine with an 8000 word memory that can be expanded to 16,000 words. The requirements and estimated margins for the Abort Electronics Assembly remain undefined.

The bulk of computer programs for both the Command Module Computer (CMC) and the LM Guidance Computer (LGC) would be a subset of those needed for Apollo. Their memory margins were determined in the following manner. Reference 1 was used as the basic source of programs required for a lunar landing mission. Since the ATM Alternative Mission is earth orbital, the first step was to delete those programs that were used only in the lunar phase or transfer phase of the lunar landing mission and which do not have an analogous use in earth orbit. (Reference 2 was used as an additional guideline for making deletions.) Also deleted from both the CMC and the LGC was the System Test Program (P07) since MSC tentatively plans to perform this function by a ground computer for AAP. In the LGC, the Abort Guidance System Initialization Routine (R47) was not deleted because a similar capability might be needed if the AGS is used for this mission. Other than these exceptions, all programs and routines were retained. For this reason the margins cited for the CMC and LGC can be considered to be conservative. The programs carried over from Apollo and those deleted are given in Tables 2, 3, 4 and 5. Table 6 shows the CMC and the LGC margins of 6045 and 9301 words, respectively, and compares them with the Apollo margins that existed for the Colossus and Luminary computer programs on March 26, 1968.

The AAP margins reflect only previously known requirements. As such, they do not include any potential new programs, such as "2 1/2 stages to orbit" for the CMC, or "unmanned rendezvous" for the LGC. The necessity for the "2 1/2 stages" program is uncertain at this time. It appears now that it would be required for the proposed 56-day mission, but not for the 28-day mission. Even if this program is necessary, CMC memory requirements are not expected to use all or even most of the 6000 word pad. Although the computer program requirements for unmanned rendezvous have not been specified, the memory requirements should not approach the otherwise large 9000 word memory reserve of the LGC. Furthermore, although it is unlikely to be needed, the LGC margin is large enough to accommodate the ATMDC requirements.

C. Comments on Spaceborne Computers

There appear to be ample margins in memory capacities of the spaceborne computers for the ATM Alternative Mission. Speed margins also appear to be adequate at present, since the LVDC, LGC, and CMC requirements will be for the most part a subset of Apollo programs. The potential new software such as for unmanned rendezvous and 2 1/2 stages to orbit will probably not cause any speed problems either, in the judgement of the authors, but further definition of their requirements is necessary before this can be confirmed. The new ATMDC is sized to provide a considerable speed margin for handling present requirements, so there is no problem with it either.

Lead times for developing new spaceborne software packages such as would be needed for 2 1/2 stages to orbit are reported as 23 months for MSC programs and 22 months for MSFC programs. In summary, there are no significant problems which have been found for spaceborne computers for the ATM Alternative Mission.

II. MCC-H COMPUTER SYSTEMS

A. General Functions

There are three principal mission-related computer systems at MCC-H: The Real Time Computer Complex (RTCC), which computes trajectories, monitors and formats telemetry, drives displays, and initiates commands; the Communications, Command, and Telemetry System (CCATS), which interfaces between the RTCC and remote sites and centers; and the Simulation, Checkout, and Training System (SCATS), which is used to train flight controllers and check out procedures. These systems are used with a variety of control rooms, the principal ones being the Mission Operations Control Rooms.

B. Constraints on AAP Missions

The impact of any mission on the MCC-H can only be determined by evaluating it in the context of other activities supported in the same time frame. The present capability of the MCC-H systems is described in References 3 and 4, along with discussions of how augmenting the current systems could provide expanded capability. It is shown that the constraints on control center usage are primarily imposed by the number of control rooms (two presently), the number of real time computers (five presently) and the computer time available for program development.

The following list, based on Reference 3, summarizes the constraints imposed by the MCC-H system:

1. Total data flow into and out of the MCC-H at any instant of time must be limited to data equivalent to that from the Apollo Launch Data System plus 12 high speed data lines to avoid overloading the CCATS.

2. Launches should be at least ten days apart to avoid overloading the Simulation Checkout and Training System (SCATS); the restriction does not apply to those dual launch missions that can be controlled from a single Control Room.

3. A mission must be no more complex than the Apollo lunar landing mission in terms of display requirements and computer loading to avoid overloading the RTCC computers.

4. No more than two missions [a dual mission that can be controlled from a single Control Room counts as one] may be conducted simultaneously -- limited by the number of Control Rooms.

5. No more than two missions [a dual mission that can be controlled from a single Control Room counts as one] can be supported within 85 days -- limited by the number of Control Rooms and their turnaround time.

6. The most demanding phases of two Apollo-like missions must not overlap to avoid overloading the display system.

These constraints are not peculiar to the ATM Alternative Mission; rather, they apply to all Apollo and AAP missions. In our opinion, the alternative mission can be supported from a single Control Room. Hence it can be flown at the same time as an Apollo mission. However, the constraints rule out flying the mission simultaneously with an independent Orbital Workshop mission and an Apollo mission, but this combination is not very likely to occur. Thus the MCC-H systems do not place any particularly difficult constraints on the ATM alternative mission. The lead time to develop MCC-H software for this mission should be about one year from the time requirements are defined.

III. CONCLUSION

Although this study was rather superficial, no serious or even potentially serious problems were discovered. It therefore is concluded that the spaceborne and MCC-H computer systems

should present no significant problems for the ATM Alternative Mission above those existing for the baseline AAP.

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1031-BHL-cak
PSS

R. T. Kleiner

R. T. Kleiner

Burt H. Liebowitz

B. H. Liebowitz

P. S. Schaenman

P. S. Schaenman

REFERENCES

1. Fixed Memory Word Budgets for Luminary and Colossus as of March 25, 1968, MIT Instrumentation Laboratory Computer Printout.

2. "Spacecraft Computer Memory Requirements for AAP," Case 600-2, J. R. Birkemeier, July 17, 1967, Bellcomm Memorandum for File.

3. "Summary of Bellcomm GOSS Augmentation Study," Case 103-1 I. D. Nehama, Sept. 25, 1967, Bellcomm Memorandum for File.

4. "Augmentation Requirements for Mission Control and Training Computers in the MCC-H," Case 103, Feb. 23, 1968, J. R. Birkemeier and B. H. Liebowitz, Bellcomm Memorandum for File.

TABLE 1

Memory Margins of Spaceborne Computers for ATM Alternative Mission

Computer	Memory Capacity	Carried over from Apollo	Margin
LVDC	12,000 Duplex* Words (expandable to 16,000)	11,250 Duplex Words	750 Duplex Words (+4000 Duplex Words expansion capability)
CMC	36,864 Words	30,819 Words	6,045 Words
LGC	36,864 Words	27,564 Words	9,301 Words
ATMDC	8000 Words (expandable to 16,000)	---	4000 Words (+8000 Words expansion capability)
AEA	4000 Words	?	?

*One duplex word means one word redundantly stored in two memory locations. All other figures in this table are for simplex memories.

TABLE 2

CMC Software Retained

UTILITY AND SERVICE PROGRAMS	COMPUTER WORDS
INTERPRETER, SINGLE PRECISION SUBROUTINES, FIXED-FIXED CONSTANT POOL	2199
EXECUTIVE	337
WAITLIST, LONGCALL	238
INTERRUPT LEAD INS	58
INTERBANK COMMUNICATION	88
T4RUPT	791
SXT ANG MON	42
KEYRUPT-UPRUPT	68
DOWNLINK PROGRAM AND 5 LISTS	395
FRESH START AND RESTART	387
ALARM AND ABORT	63
DELAYJOB	30
RESTART ROUTINE AND TABLES	401
PHASE TABLE MAINTENANCE	183
PINBALL PROGRAM AND NOUN TABLES	2905
DISPLAYS, PRIOLARM	679
PROGRAM SELECT, POO, ROO	283
SELF CHECK	314
EXTENDED VERBS	562
RTB OP CODES	178
SXTMARK	307

TABLE 2 (continued)

CMC Software Retained

UTILITY AND SERVICE PROGRAMS (continued)	COMPUTER WORDS
IMU MODE SWITCHING	571
IMU COMPENSATION	246
CMC STARTUP	32
CMC POWER DOWN (P06)	48
IMU STATUS CHECK	17
INTERPRETIVE CONSTANTS	35
FLAGUP, FLAGDOWN	63
GENTRAN	15
DAP DATA LOAD (R03)	29
END BANK MARKERS	79
SUBTOTAL	11643
AUTOPILOT AND MANEUVER PROGRAMS	
DAP ENTRY	823
DAP BOOST	63
DAP RCS	1795
DAP TVC	1653
S40.6	68
TVNG	26
KALCMANU	711
ATTITUDE MANEUVER (R60)	83
CREW DEFINED MANEUVER (R62)	11

TABLE 2 (continued)

AUTOPILOT AND MANEUVER PROGRAMS (continued)		COMPUTER WORDS
VECPOINT		130
RENDEZVOUS FINAL ATTITUDE (R63)		40
MIDDLE GIMBAL DISPLAY		64
CM BODY ATTITUDE		195
	SUBTOTAL	5662
BASIC MATH ROUTINES		
INFLIGHT ALIGNMENT ROUTINES		225
POWDERED FLIGHT SUBROUTINES		159
CSM GEOMETRY		254
TIME OF FREE FALL		264
CONIC SUBROUTINES		1093
ORBITAL INTEGRATION		1490
PERIAPO		78
LATITUDE, LONGITUDE, ALTITUDE		159
INITIAL VELOCITY		175
LUNAR AND SOLAR EPHEMERIS		71
PLANETARY INERTIAL ORIENTATION		204
	SUBTOTAL	4172
TARGETING ROUTINES		
CENTRAL ANGLE SUBROUTINE		40
	SUBTOTAL	40
NAVIGATION ROUTINES		
MEASUREMENT INCORPORATION		333

TABLE 2 (continued)

NAVIGATION ROUTINES (continued)	COMPUTER WORDS
PREFERRED TRACKING ATTITUDE (R61)	270
RENDEZ TRKG SGHTNG MARK + BCKUP	66
RENDEZ TRKG DATA PROCESS + BCKUP	450
SUBTOTAL	1119
POWERED GUIDANCE ROUTINES	
SERVICER	423
DESIRED THRUST DIRECTION	299
CROSS PRODUCT STEERING	134
VG CALCULATION	113
TIME OF BURN CALCULATION	79
INITIAL VG	17
ENTRY GUIDANCE	1117
SUBTOTAL	2182
ALIGNMENT ROUTINES	
COARSE ALIGN (R50)	74
FINE ALIGN (R51)	116
AUTO OPTICS (R52)	126
SIGHTING MARK (R53)	47
STAR DATA TEST (R54)	41
GYRO TORQUING (R55)	27
PICK-A-PAIR	127
STAR CATALOG	223
ALTERNATE IOS SIGHTING MARK (R56)	118

TABLE 2 (continued)

ALIGNMENT ROUTINES (continued)	COMPUTER WORDS
OPTICS CALIBRATION (R57)	48
SUBTOTAL	947
MISCELLANEOUS PROGRAMS AND ROUTINES	
P27 - UPDATE PROGRAM	306
R36 - REND OUT OF PLANE DISPLAY	91
P30-P31 - EXT DELT V+GEN LAMBERT MAN	288
R05 - S BAND ANTENNA DISPLAY	80
R30 - ORBIT PARAMETER DISPLAY	260
R31-R34 REND PARAM DSPLA ROUT 1+2	170
R32 - TARGET DELTA V	97
R33 - CMC/LGC CLOCK SYNCHRONIZATION	26
SUBTOTAL	1318
MISSION CONTROL PROGRAMS	
P01 - PREL OR SERV INITIALIZATION	38
P02 - PREL OR SERV GYROCOMPASSING	328
P03 - OPTICAL VERIF OF GYROCOMP	177
P11 - EARTH ORBIT INSERTION MONITOR	399
P20 - RENDEZVOUS NAVIGATION	140
P21 - GROUND TRACK DETERMINATION	66
P34, 35, 74, 75 TP PRETHRUST	643
P38, 39, 78, 79 SOR+SOM PRETHRUST	231
P40-P41 SPS+RCS THRUSTING	601

TABLE 2 (continued)

MISSION CONTROL PROGRAMS (continued)	COMPUTER WORDS
P47 - THRUST MONITOR	43
P51, P53 - IMU ORIENT DETERM + BACKUP	256
P52, P54 - IMU REALIGN AND BACKUP	373
P61 - MANEUVER TO CM/SM SEP ATT	307
P62 - CM/SM SEP + PRE-ENT MANEUVER	80
P63 - ENTRY INITIALIZATION	16
P64 - POST 0.05G	6
P67 - FINAL PHASE	32
SUBTOTAL	3736
GRAND TOTAL	30819
COMPUTER MEMORY (FIXED)	36864
PAD REMAINING FOR AAP	6045

TABLE 3

LGC Software Retained

UTILITY AND SERVICE PROGRAMS	COMPUTER WORDS
INTERPRETER, SINGLE PRECISION SUBROUTINES, FIXED-FIXED CONSTANT POOL	2199
EXECUTIVE	337
WAITLIST, LONGCALL	238
INTERRUPT LEAD INS	58
INTERBANK COMMUNICATION	88
T4RUPT	612
KEYRUPT-UPRUPT	68
DOWNLINK PROGRAM AND 5 LISTS	354
FRESH START AND RESTART	407
ALARM AND ABORT	63
DELAYJOB	30
RESTART ROUTINE AND TABLES	293
PHASE TABLE MAINTENANCE	183
PINBALL PROGRAM AND NOUN TABLES	2919
DISPLAYS, PRIOLARM	679
PROGRAM SELECT, POO, ROO	301
SELF CHECK	314
EXTENDED VERBS	483
RTB OP CODES	178
RADAR RUPTS	181
AOTMARK (R53)	386
COAS BACKUP MARKING	15
IMU MODE SWITCHING	571
IMU COMPENSATION	267

TABLE 3 (continued)

UTILITY AND SERVICE PROGRAMS (continued)		COMPUTER WORDS
LGC STARTUP		32
LGC POWER DOWN (P06)		48
IMU STATUS CHECK		17
INTERPRETIVE CONSTANTS		35
FLAGUP, FLAGDOWN		63
GENTRAN		15
DAP DATA LOAD (R03)		139
RADAR SUBROUTINES		739
END BANK MARKERS		72
	SUBTOTAL	12384
AUTOPILOT AND MANEUVER PROGRAMS		
DIGITAL AUTOPILOT		2966
KALCMANU		670
FINDCDUW		282
ATTITUDE MANEUVER (R60)		124
CREW DEFINED MANEUVER (R62)		11
VECPOINT		130
RENDEZVOUS FINAL ATTITUDE (R63)		67
BALL ANGLE DISPLAY		49
	SUBTOTAL	4299
BASIC MATH ROUTINES		
INFLIGHT ALIGNMENT ROUTINES		227
POWERED FLIGHT SUBROUTINES		159
LEM GEOMETRY		99
TIME OF FREE FALL		264

TABLE 3 (continued)

BASIC MATH ROUTINES (continued)	COMPUTER WORDS
CONIC SUBROUTINES	1093
ORBITAL INTEGRATION	1496
PERIAPO	78
LATITUDE, LONGITUDE, ALTITUDE	159
INITIAL VELOCITY	175
LUNAR AND SOLAR EPHEMERIS	126
PLANETARY INERTIAL ORIENTATION	204
SUBTOTAL	4080
NAVIGATION ROUTINES	
MEASUREMENT INCORPORATION	333
PREFERRED TRACKING ATTITUDE (R61)	37
RENDEZVOUS NAVIGATION AND LSR22.3, RADARANG	
LUNAR SURFACE NAVIGATION AND LSR22.4	480
RR SEARCH, DESIGNATE AND READ R21, R22, R23, R24 LPS20.1, LPS20.2, LRS22.1, LRS22.2, LRS24.1, CALCXY	627
SUBTOTAL	1477
POWERED GUIDANCE ROUTINES	
SERVICER	983
DESIRED THRUST DIRECTION S40.1, S40.2, 3	117
CROSS PRODUCT STEERING (S40.8)	60
VG CALCULATION (S40.9)	99

TABLE 3 (continued)

POWERED GUIDANCE ROUTINES (continued)	COMPUTER WORDS
TIME OF BURN CALCULATION (S40.13)	118
TRIMGIMB, S41.1	54
SUBTOTAL	1431
ALIGNMENT ROUTINES	
COARSE ALIGN (R50)	61
FINE ALIGN (R51)	103
AUTO OPTICS (R52)	65
STAR DATA TEST (R54)	41
GYRO TORQUING (R55)	27
PICK-A-PAIR	132
STAR CATALOG	223
SUBTOTAL	652
MISCELLANEOUS PROGRAMS AND ROUTINES	
R47 - AGS INITIALIZATION	114
R36 - RENDEZVOUS OUT OF PLANE DISPLAY	91
P27 - UPDATE PROGRAM	306
P30 - EXTERNAL DELTA V PRETHRUST	97
P31 - GENERAL LAMBERT MANEUVER	93
R04 - RR/LR SELF TEST AND	145
R77 - LR SPURIOUS RETURN TEST	
R05 - S BAND ANTENNA DISPLAY	99
R30 - ORBIT PARAMETER DISPLAY	260
R31 - RENDEZVOUS PARAMETER DISPLAY	170
R32 - TARGET DELTA V	97

TABLE 3 (continued)

MISCELLANEOUS PROGRAMS AND ROUTINES (continued)		COMPUTER WORDS
R33 - CMC/LGC CLOCK SYNCHRONIZATION		26
R13 - AUTO MODES MONITOR		36
	SUBTOTAL	1534
MISSION CONTROL PROGRAMS		
P20 RENDEZVOUS NAVIGATION		202
P21 GROUND TRACK DETERMINATION		66
P25 PREFERRED TRACKING ATTITUDE		54
P34-P74 TP PRETHRUST		642
P38, 39, 78, 79 SOR, SOM PRETHRUST		224
P41 RCS THRUST		47
P47 THRUST MONITOR		52
P51 IMU ORIENTATION		263
P52 IMU REALIGNMENT		156
	SUBTOTAL	1706
	GRAND TOTAL	27563
COMPUTER MEMORY (FIXED)		36864
PAD REMAINING FOR AAP		9301

TABLE 4

CMC Software Deleted

		Computer Words
Utility and Service Routines		
	System Test (P07)	626
	Subtotal	626
Targeting Routines		
	TPI Search	313
	Subtotal	313
Navigation Routines		
	Lunar Landmark Selections (R35)	210
	Landmark Table	150
	Subtotal	360
Mission Control Programs		
	P15 Translunar Injection	---
	P17 TPI Search	70
	P22 Orbital Navigation	1015
	P23 Cislunar Miscourse Navigation	554
	P37 Return to Earth	1258
	P65 Upcontrol	22
	P66 Ballistic	9
	P77 LM TPI Search	---
	Subtotal	2928
	Grand Total	4227

TABLE 5

LGC Software Deleted

	Computer Words
Utility and Service Programs	
System Test (P07)	628
Subtotal	628
Autopilot and Maneuver Programs	
Middle Gimbal Display	64
Subtotal	64
Targeting Routines	
Coelliptic Sequence Initiation	649
Constant Delta Altitude	---
Subtotal	649
Powered Guidance Routines	
Descent Guidance	759
Throttle Logic	112
Ascent Guidance	512
Subtotal	1383
Miscellaneous Programs and Routines	
R10-LNDG Analog Display Monitor	480
R11-Abort Discretes Monitor	34
Subtotal	514
Mission Control Programs	
P10-P11 Predicted Launch Time	441
P12 Ascent Guidance	139
P22 Lunar Surface Navigation	18
P32-P72 CSI Prethrust	93
P33-P73 CDH Prethrust	136
P40 DPS Thrust	967

TABLE 5 LGC Software Deleted-Continued

P42 APS Thrust		16
P57 Lunar Surface Align		494
P63 Landing Braking		166
P64 Landing Approach		---
P65, P66, P67		121
P70 DPS Abort		195
P71 APS Abort		118
	Subtotal	2904
	Grand Total	6142

TABLE 6

Comparison of Apollo and AAP Memory Pads

I. Command Module Computer

	Apollo (Colossus, as of 3/26/68)	AAP
Computer Memory Capacity (Fixed)	36864 Words	36864 Words
Words Utilized	35046	30819
Pad Remaining	1818	6045

II. LM Guidance Computer

	Apollo (Luminary, as of 3/26/68)	AAP
Computer Memory Capacity (Fixed)	36864 Words	36864 Words
Words Utilized	33705	27564
Pad Remaining	3159	9301